

The pseudoepiphysis of the first metacarpal of man

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INTRODUCTION

The metacarpals have long interested anatomists. Most early authorities, including Aristotle and Celsus, mentioned by Uffelmann (1863), reckoned, as do recent workers, 5 in each hand, with 2 phalanges in the pollex and 3 in the other digits. But Galen, in his *Osteology for Beginners*, widely read in Sylvius' (1561) Latin translation and now available in English by Singer (1952), allowed only 4 metacarpals. He identified the basal bone of the pollex as a phalanx on account of its mobility, true metacarpals being attached more rigidly to the carpus by 'synarthrosin', not 'diarthrosin'. This would give a uniform 3 phalanges, a basal, middle and terminal in each digit.

Vesalius (1543), who accepted Galen's view, described epiphyseal centres, his 'appendices', at both ends of the metacarpals. But Nesbitt (1736) and others found the bony substance of the head of the first metacarpal developed by a direct extension of the shaft, in contrast to the base where a true epiphyseal centre was formed, separated from the shaft by a continuous growth plate. This arrangement corresponded to that in the phalanges, not the metacarpals, of other digits, and was often quoted in support of Galen.

The gross structure of the developing metacarpal was described by Uffelmann (1863), Thomson (1869) and Bailleul (1911), with good reviews of the literature. All gave drawings of wet specimens cut in longitudinal section, showing a mushroom-like extension of the shaft into the cartilage, with a relatively narrow vascular stalk and an expanded body supporting the convex articular surface (cf. Fig. 2). The body was separated from the shaft by a septum of cartilage, perforated, not always centrally, for the stalk. Removal of the cartilage by maceration left notches partially or completely surrounding the neck, resembling the notches often seen after epiphyses had united. Pfitzner (1890) named the mushroom-like outgrowths 'pseudoepiphyses'.

Uffelmann decided that the basal bone of the thumb was a combined metacarpal and phalanx. But with the recognition of a reptilian ancestry for mammals, the reptilian digital formula being 2, 3, 4, 5, 3 or 4, there was no longer any reason to identify a 'missing' phalanx in the pollex. Again, the evidence for opposability or semi-opposability of the pollex of early tertiary mammals, at one time advanced in support of an arboreal habit, proved unacceptable (Haines, 1958), the special mobility being a primate rather than a generalized mammalian character. So the presence of an epiphysis at the base of the metacarpal and absence at the head, found in all terrestrial mammals, could not depend on or be related to the mobility at the carpometacarpal joint, as had been suggested by Broom (1906).

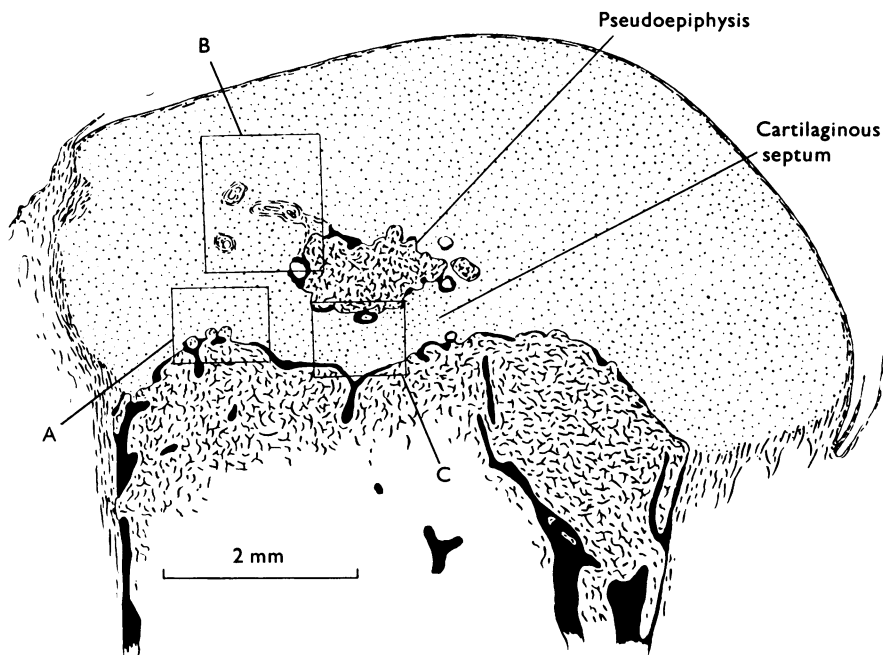


Fig. 1. Section from the head of the metacarpal of a 5 year old boy, cutting the body of the pseudoepiphysis. Bone black, cartilage stippled, fibrous tissues lined, marrow squiggled. For the areas A, B and C see Figs. 6, 7 and 16.

With the advent of radiology a literature grew up associating pseudoepiphyses with various pathological conditions. But in their longitudinal radiological study of normal children Lee & Garn (1967) found pseudoepiphyses of constant occurrence and without morbid significance. Radiographs have greatly extended knowledge of their forms and times of development. But Bailleul (1911) never published the histological sequel he intended to follow his studies of gross structure and Lee & Garn even expressed doubt concerning the tissue which filled the notches they saw. Beaumont (1967) hoped that a study of mammalian pseudoepiphyses might throw light on the growth of bird bones, which mostly grow without epiphyses.

In this paper the general morphology and histology of the metacarpal head are described with particular attention to the growth mechanisms. The material gave an unexpected opportunity for revaluation of cartilage recruitment by the cartilage canals and of interstitial cartilage growth generally.

MATERIAL AND METHODS

Pertinent material, as noted by Thomson (1869), is hard to come by. So rather poorly fixed preparations from two Ugandan boys, judged to be about 3 and 5 years old respectively, are presented. Their medical histories are not known. The metacarpal heads were cut in serial section at $10\ \mu\text{m}$ in the plane of flexion of the metacarpophalangeal joint and stained with haematoxylin and eosin. Drawings

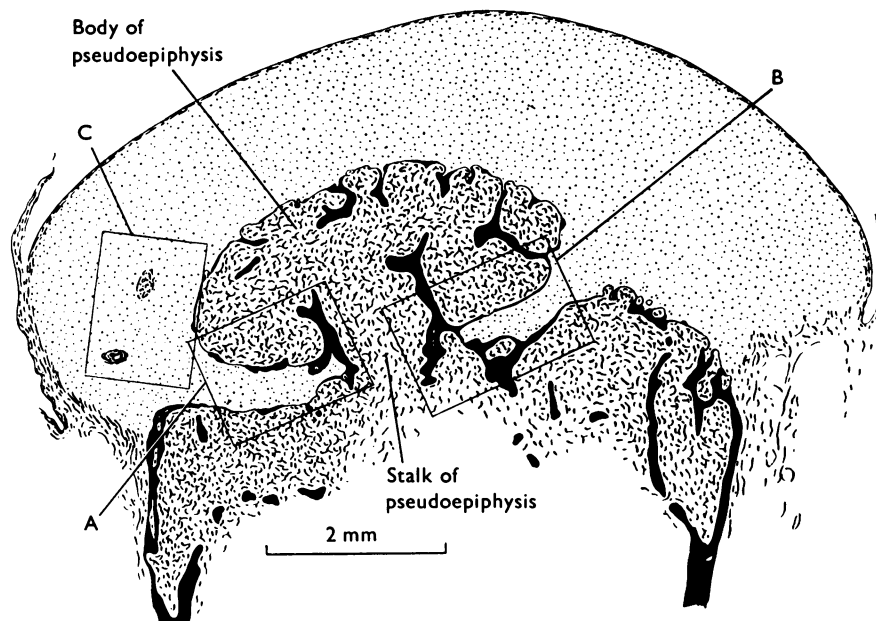


Fig. 2. As Fig. 1 but passing through the stalk. For areas A and B and C see Figs. 3, 4 and 19.

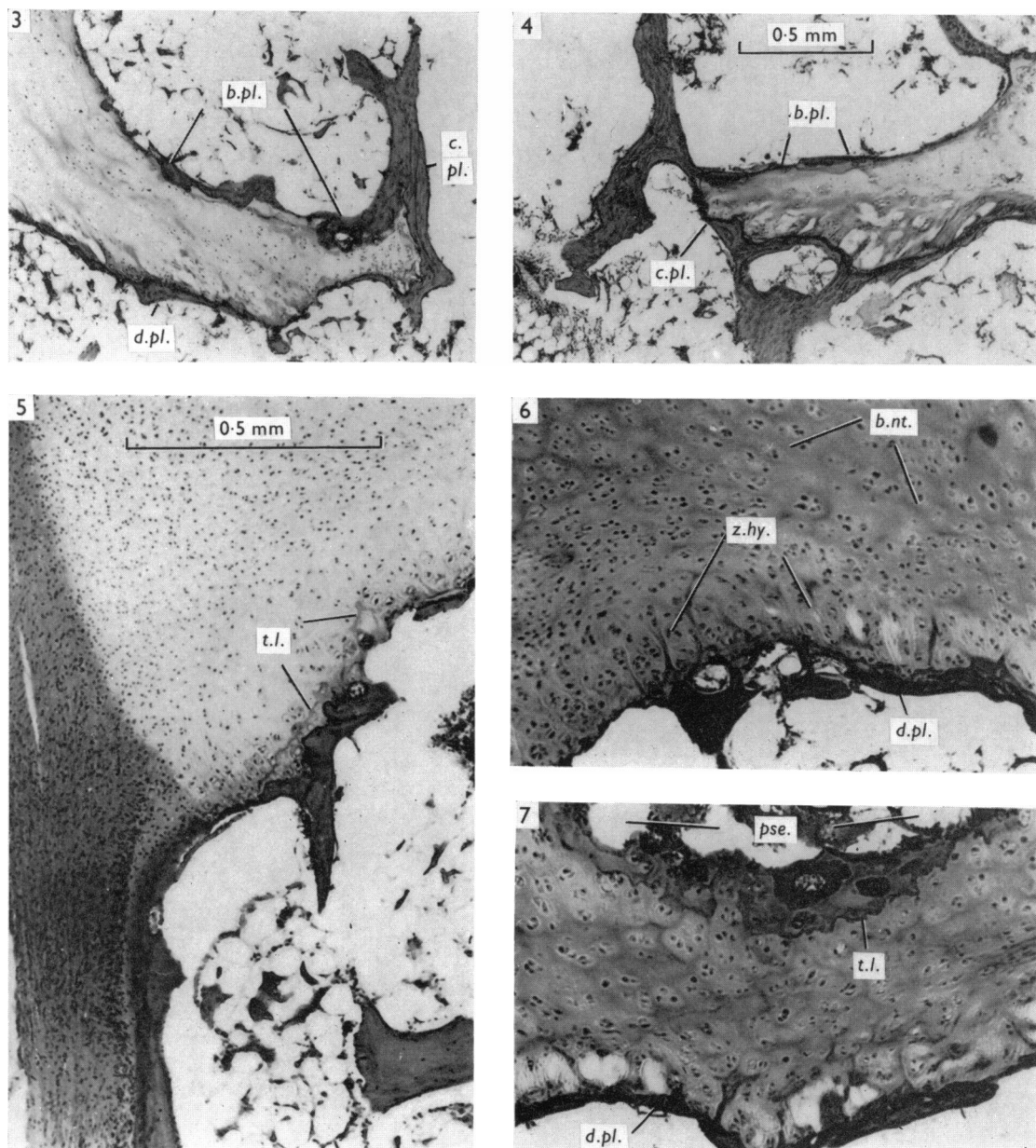
were made using a microprojector for the outlines, but filled in diagrammatically, leaving the details for microphotography. The grosser features of the bone and cartilage canals were drawn from tracing paper models.

OBSERVATIONS

The pseudoepiphysis and epiphyseal centre

A general view of a somewhat tangential section through the head of the older child's metacarpal (Fig. 1) suggests, at first sight, an ordinary epiphyseal arrangement. A bony shaft ends in a massive cartilage with a convex articular surface thinly covered with fibrocartilage, as is often the case at this stage. Within the cartilage is a mass of bone and marrow, the body of the pseudoepiphysis. A more central section (Fig. 2) shows the cartilage septum between shaft and pseudoepiphysis pierced by the stalk of the pseudoepiphysis. The stalk consists largely of marrow, but peripherally the margin of the hole in the septum is lined with bone (appearing as two plates in sections, and hence called 'capping plates': Figs. 3 and 4, *c.pl.*) which connects together the basal plate (*b.pl.*) of the pseudoepiphysis and the diaphyseal plate (*d.pl.*) of the shaft. Thus these plates are fixed to each other and cannot move apart.

The cartilage next to the shaft, though its cells are hypertrophied, has no well-defined columns (Figs. 5-7, *z.hy.*) and may show 'tide lines' (Fawns & Landells, 1953) such as are characteristically associated with the slow spread of mineralization in dense connective tissue (Fig. 5, *t.l.*). The marrow of the shaft is largely cut off from the cartilage by the diaphyseal plate of bone indicating that erosion of the cartilage



Figs. 3-7. Features of the metacarpal head of the 5 year old boy.

Figs. 3 and 4. Margins of the cartilaginous septum between the shaft and pseudoepiphysis.

Fig. 5. Tide line in hypertrophied cartilage.

Fig. 6. Diaphyseal plate between the bone marrow of the shaft and the cartilage of the head.

Fig. 7. Pseudoepiphysis with tide line.

Abbreviations for all photomicrographs: *art.*, arteriole; *b.nt.*, basophilic network; *b.pl.*, basal plate of pseudoepiphysis; *c.cm.*, cartilage column; *c.ct.*, collagenous coat; *c.pl.*, capping plate; *d.pl.*, diaphyseal plate; *ght.*, ghost; *pch.*, perichondrium; *pse.*, pseudoepiphysis; *s.c.c.*, small-celled cartilage; *t.l.*, tide line; *ven.*, venule; *z.hy.*, zone of hypertrophy.

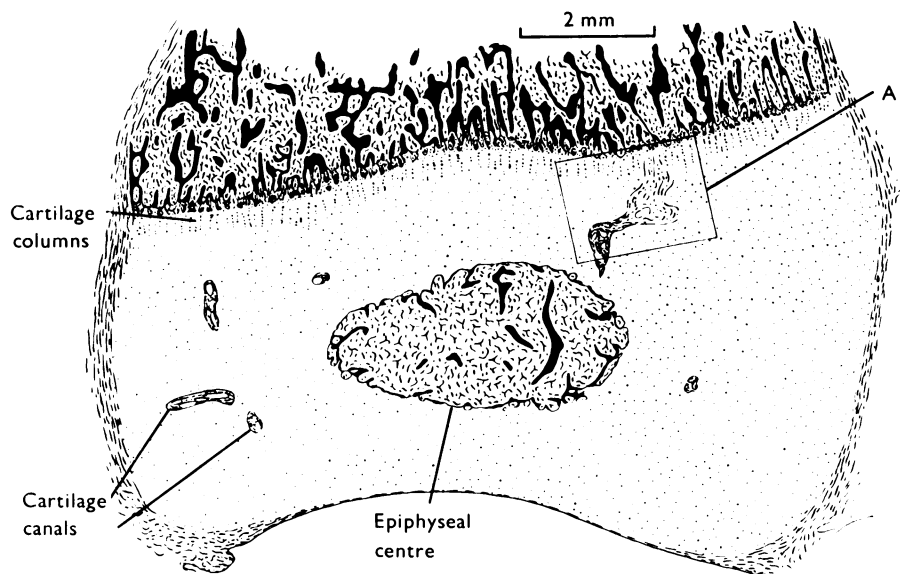


Fig. 8. Base of the 5 year old metacarpal with epiphyseal centre. For area A see Fig. 22.

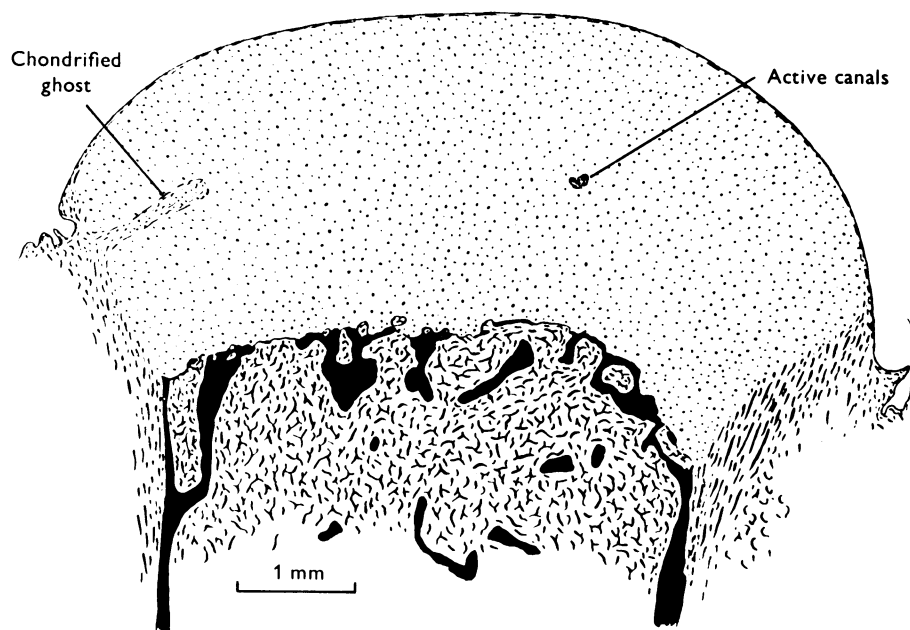


Fig. 9. Head of the 3 year old metacarpal, before the pseudoepiphysis had developed.

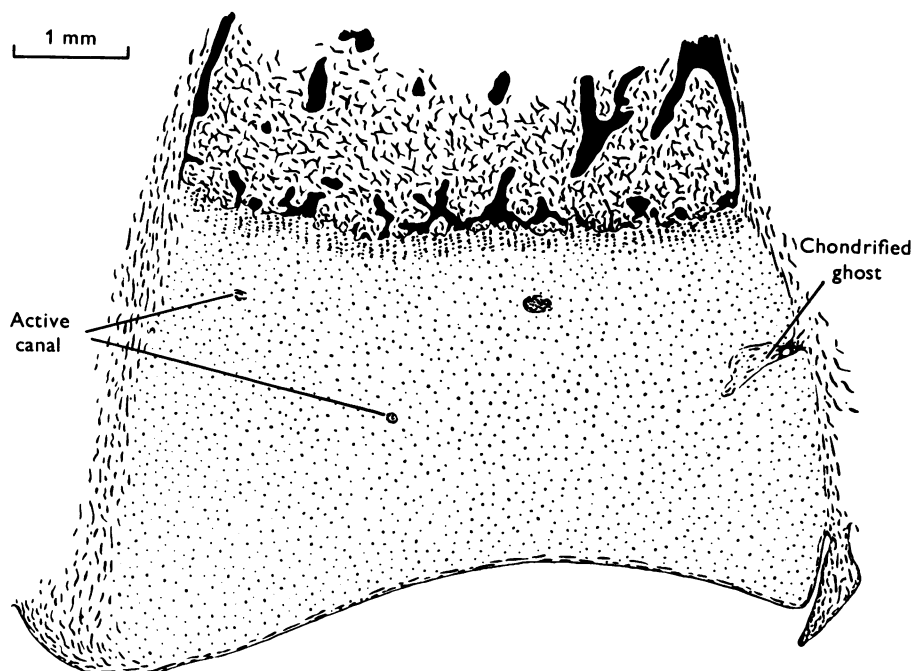


Fig. 10. Base of the 3 year old metacarpal with small vascularized cartilage canals and a swollen ghost.

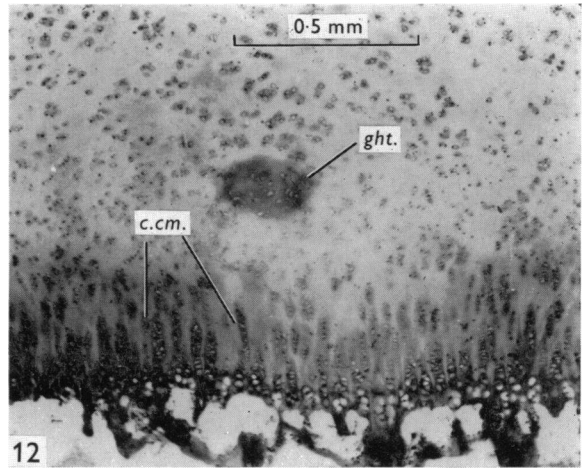
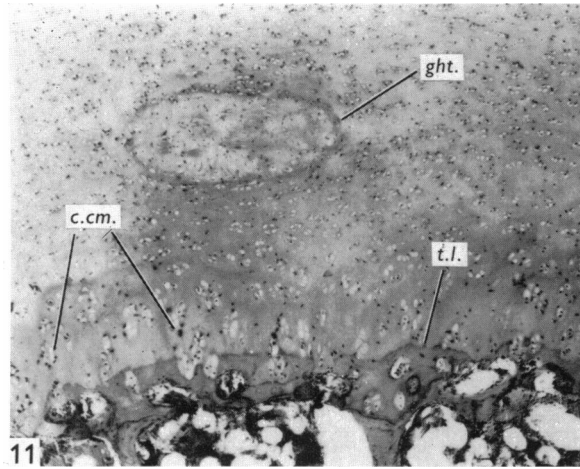
by the marrow is either absent or very restricted. The body of the pseudoepiphysis is surrounded by well marked 'tide lines' in the cartilage – a sign of a very slow rate of expansion. (Fig. 7).

The true epiphyseal centre at the other end of the metacarpal (Fig. 8) is still rounded in outline and entirely surrounded by cartilage. The presence of well developed cartilage columns and marrow sprouts, and the absence of a diaphyseal plate give evidence of the active growth of the shaft at this end.

In the younger boy neither the pseudoepiphysis nor the true epiphyseal centre has yet appeared (Figs. 9 and 10), and no differences can be found in the main masses of cartilage. But at the head, though cartilage columns are found and indicate some growth, they are short and irregular (Fig. 11, *c.cm.*) and 'tide lines', sometimes doubled, are clear (*t.l.*). At the base the columns are well developed (Fig. 12).

The cartilage canals

Some of the canals are patent, and filled with loose connective tissue and blood vessels, but others have been filled in with new cartilage, with disappearance of vessels and presumably transformation of former loose connective tissue cells into chondrocytes. The resulting 'ghost canals' are shown stippled in Fig. 13, where the canals are numbered in the order in which they are encountered in the sections. Thus canal 1, the most complex, has 5 branches, 2 of them ending in the body of the pseudoepiphysis, one ending blindly but vascularized throughout, and 2 ending in



Figs. 11 and 12. Contrast in growth activity at the two ends of the 3 year old metacarpal.
 Fig. 11. The head with poorly developed cartilage columns and a well defined tide line. A pale swollen ghost lies in the matrix.
 Fig. 12. The base with well developed and more crowded columns and a dark ghost.

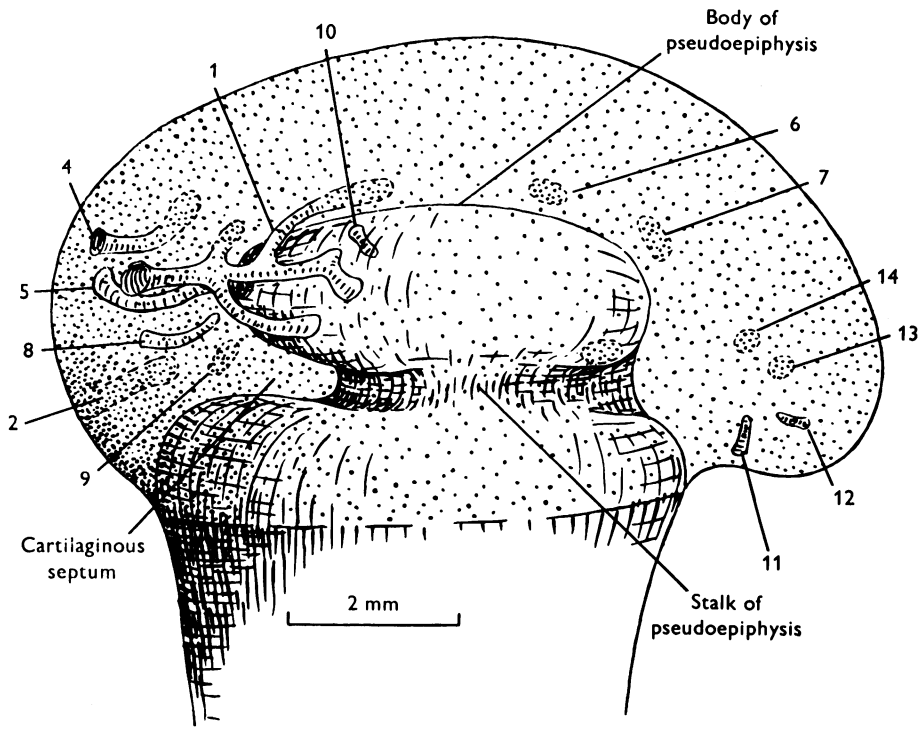
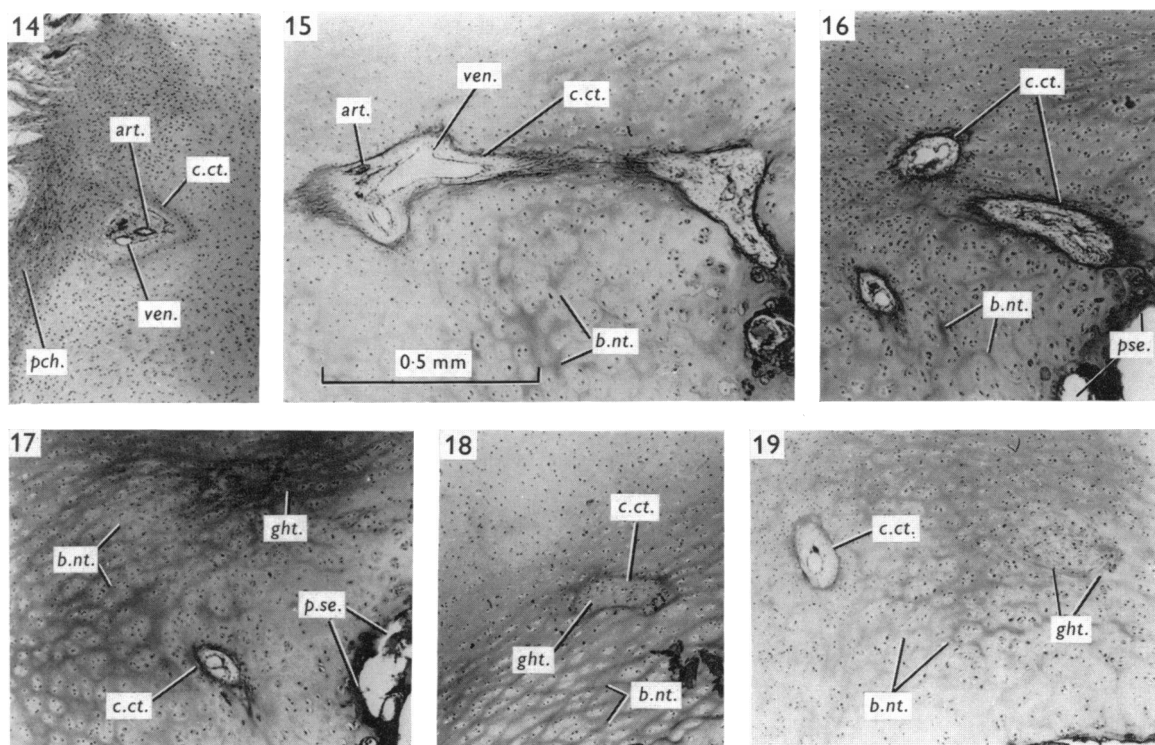


Fig. 13. The head of the 5 year old metacarpal modelled in tracing paper to show the pseudoepiphysis within the cartilage and the canal system. Vascularized canals shown lined, ghosts stippled.



Figs. 14-19. Cartilage canals and their chondrification. Figs. 14-17 are from the same canal.

Fig. 14. Entry from the perichondrium.

Fig. 15. Body of the canal.

Fig. 16. Branch entering body of pseudoepiphysis.

Fig. 17. Two branches, one a ghost.

Fig. 18. Ghost and well developed basophilic network.

Fig. 19. Faint ghost.

'ghosts'. At its external end the canal contents continue into the perichondrium with continuity of blood vessels and connective tissue. The stem of the vascular-connective tissue tree within the branching canal (Fig. 14) has a well developed collagenous coat (*c.ct.*), the 'hülsenförmige Zone' of Kajava (1919). This coat continues into the vascularized branches (Fig. 15) and reaches the bony centre (Fig. 16). Figure 17 shows two branches side by side, one with the vessels open and the coat well defined, the other a 'ghost' (*ght.*) without vessels, but with remains of the original fibrous contents and a fading coat. In Fig. 18, from canal 6, all the remaining cells have become chondrocytes, similar to those of the cartilage around them, but smaller and more crowded; and the fibrous coat, though impregnated with cartilage matrix, is still clear. In Fig. 19, from canal 4, it would be difficult to identify the ghost if it were not in continuity with the vascularized base. Canal 2 is chondrified throughout, while others persist only as isolated remnants which have lost connexion through to

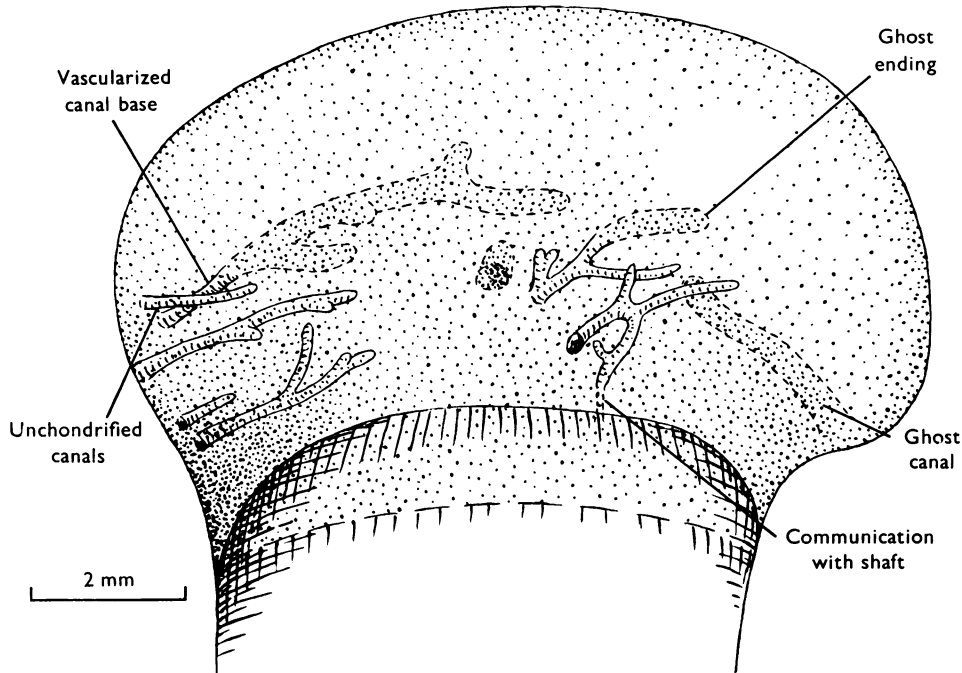


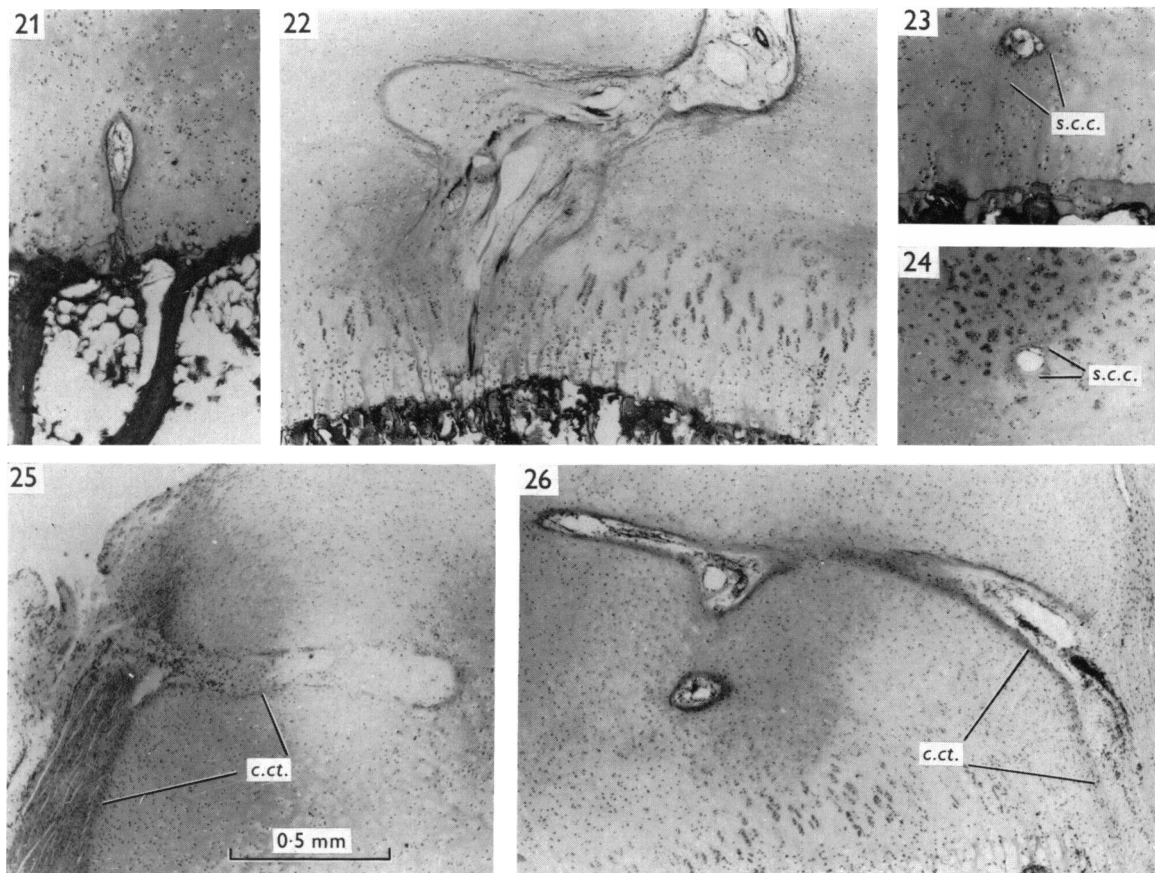
Fig. 20. Canals in the cartilaginous head of the younger metacarpal.

the perichondrium (the 'floating ghosts'). Many of these ghosts, and the whole length of canal 2, are wider than the canals which are still vascularized.

In the metacarpal head of the younger child (Fig. 20) the canals are similar, and their chondrification again conspicuous. One of the canals has become caught up in the growth zone (Fig. 21) and is drawn out to form a connexion with the shaft, affording further evidence of continuing growth at this stage. At the base of the metacarpal the canals are again similar, but there is no indication that a true epiphyseal centre, rather than a pseudoepiphysis, will appear later. Associated with more active growth, several canals are connected to the shaft. Fig. 22 shows one of these open vessels, and a well marked collagen sheath passing into a swollen chondrified part, and this in turn is drawn out as it enters the zone of cartilage columns.

The small-celled cartilage and basophilic network

A peculiar type of cartilage with small, closely-packed cells is often found in the immediate vicinity of cartilage canals, as in Figs. 23 and 24 (*s.c.c.*). In canals cut longitudinally (Figs. 25, 26) the collagen coat (*c.ct.*) can often be followed into the deepest layer of the perichondrium and the small-celled cartilage into the subperichondrial cartilage. More widespread is a basophilic network found in the ground substance of the older cartilage, near the canals, shown in Figs. 15–19, similar to the 'trainées à prolongements radiés dans la substance fondamentale du cartilage' found by Retterer (1900) in the matrix of the costal cartilages of young cats and dogs and the 'blauen Balkennetze' figured by Kajava (1919) in human material.



Figs. 21-26. Features of cartilage canals.

Fig. 21. Canal from the younger head with a narrow prolongation to the shaft.

Fig. 22. Canal from the older base with chondrification and a broad prolongation to the shaft.

Figs. 23 and 24. Vascularized canals with associated small-celled cartilage from the younger head and base.

Fig. 25. Ghost canal, cut longitudinally, from the younger head.

Fig. 26. Longer canal from the older base, its walls continued into the perichondrium.

DISCUSSION

Fetal metacarpals show no marked differences in growth at the two ends. In the younger of the two bones studied, growth between the cartilaginous head and the shaft was slowed, as shown by the poorly developed cartilage columns and the presence of tide lines. In the older, the head was largely occupied by a bony pseudoepiphysis rigidly joined by a stalk to the shaft, so that no further displacement of the head relative to the shaft was possible. The slowing (certainly) and the stoppage (probably) precede the formation of a pseudoepiphysis, and appear to explain its formation more convincingly than theories based on a supposed phalangeal nature

of the bone, or on the kinds of joint in which the bone takes part. While the growth cartilage is still active and shows well defined cartilage columns, the metacarpal head behaves as an ordinary cartilaginous epiphysis. But when the cartilage stops growing and presumably no longer acts as a barrier, the marrow of the shaft breaks through and invades the head to form a pseudoepiphysis. Bailleul (1914) described a pollex with 3 phalanges. The metacarpal was relatively long and resembled the other metacarpals in having a true epiphysis at the head and a pseudoepiphysis at the base, again suggesting dependence of bony structure on mode of growth rather than on phylogeny or joint function. Ideas about mammalian pseudoepiphysis cannot be extended to bird bones, for their growth is very rapid at the nestling stage, giving little opportunity for pseudoepiphysis formation.

Radiographs show, in some individuals, the body of the pseudoepiphysis appearing before the stalk (Bailleul, 1911; Lee & Garn, 1967). But of course a stalk consisting of marrow only would not appear in radiographs. It is, however, conceivable that an independent centre of ossification might be formed from the tissues of the canals like a true epiphysis, and that the stalk is a secondary connexion.

Vascular channels in hyaline cartilage were described and figured by Nesbitt (1736) in 'an epiphysis ossis femoris just before the bony particles become visible in it'. Hunter (1743) injected them in a duckling, and Howship (1815) named them 'cartilaginous canals'. Their precise arrangement was studied by Hintzsche (1927, 1931), Haines (1933, 1937), Hurrell (1934) and Hintzsche & Schmid (1933), using reconstructions from serial sections, and by Trueta (1957), Haraldsson (1962), Levene (1964) and others, using injection techniques.

Besides their obvious function of cartilage nutrition, they seem to determine the position of secondary centres of ossification (Haines, 1933; but denied by Levene, 1964), provide material for the formation of these centres, and carry nutrition to them in early development. They also, by chondrification of their content, add to the volume of the cartilages, injecting new material into the substance of the old (Kajava, 1919). The chondrification is usually regarded as a form of degeneration, a 'Rückbildung', resulting in (relatively rare) 'ghost canals', rather than as providing a significant source of new cartilage.

The metacarpal material and its interpretation presented here are in close accord with Kajava's (1919) work, and with his insistence on chondrification. But it is difficult to explain the abundance of evidence for chondrification in the metacarpal, as compared with its apparent rarity in other bones described in the literature. Hintzsche (1931), for example, in a careful search found only one chondrified canal in the head of the radius and three in the upper end of the ulna of a newborn baby. Possibly the slower growth of the metacarpal head leads to less rapid remodelling and disturbance of the cartilage, so that the ghosts persist longer.

The 'floating ghosts' were presumably once parts of active canals, vascularized throughout, and their presence implies the complete disappearance of the intermediate parts and the possibility that whole canals may be lost without trace. The swollen appearance of the ghosts, both floating and attached, suggests that the canals provide considerably more new cartilage than their own original volume when patent.

Retterer (1900), in his classic account of cartilaginous structures, called attention to the zone of small cells often found near canals and seemingly in a state of

proliferation. He suggested that they were derived from typical large cartilage cells as the canals spread into the cartilage by chondrolysis, the matrix dissolving away, the fibres becoming unmasked, and the cells becoming first smaller and then transforming into young connective tissue cells. Most later workers have held similar views. For example Hurrell (1934) figured a canal surrounded by small cells as 'still actively growing', and Lutfi (1970) described the cartilage as 'reverting to mesenchymal tissue around the vessels'. Beaumont (1967) noted in his excellent chick material that 'single cartilage cells are found in the immediate vicinity of the vascular bundle, but further away they appear first in pairs, and then in groups of four', again suggesting cell multiplication.

But the canal tissues can be followed, with no marked change, into the perichondrium. If, as is generally believed, the perichondrium continually adds to the cartilage during growth by chondrification of its deeper layers, the canals would appear to be doing the same. The collagen coat would then consist of fibres formed in the canal wall and about to be added to the cartilage substance and masked by its matrix, and *not* of fibres derived from the matrix by unmasking. Electron microscopy, unfortunately, though confirming the collagenous nature of the coat, 'gives little information' concerning its mode of formation (Stockwell, 1971). The small cells near the canal would be young cells derived from it, and would have limited powers of division, as do the similar cells derived from the perichondrium. In lizards the new cartilage is particularly well defined, appearing as 'hyaline haloes' surrounding the canals (Haines, 1969).

The canals then appear to contribute to the cartilage both by progressive transformation of their walls and, at length, by solid chondrification of their interiors.

Hintzsche (1927) and Hurrell (1934) pointed out that if the canals were passively included in the cartilage, as postulated by the 'inclusion theory', this would imply extensive remodelling of the cartilage matrix to provide the complex branching systems. Finding no evidence of such remodelling they rejected the inclusion theory in favour of chondrolysis. The basophilic network may, however, provide the evidence; for van den Hooff (1964) has suggested that the intense basophilia near the rapidly expanding ends of cartilage columns in the growth zones of epiphyses may be due to the destruction of the hexose bonds uniting the collagen fibres, allowing the fibres to slip past each other. Haines (1969) found extensive networks in turtles where the cartilaginous epiphyses were known to be expanding and Lutfi (1970) showed it associated with an obliterated canal in the chick. It is therefore possible that the basophilia of the network is associated with the freeing of the collagen fibres necessary for the remodelling of the older cartilage as the canals are elaborated and new cartilage formed. However, it must be admitted that much remains to be discovered about the bonding of collagen and mucopolysaccharides.

SUMMARY

Two first metacarpal heads, one at a stage before the appearance of either the epiphyseal centre at the base or the pseudoepiphysis at the head, the other after the appearance of both, were examined by microscopy and the cartilage canals modelled.

In the younger head, cartilage columns were poorly developed and tide lines were

found in the matrix of the growth plate, suggesting that growth was slow as compared with growth at the base where the columns were well developed.

In the older head, a mushroom-like pseudoepiphysis sprang by a narrow bony stalk from the shaft, and, since the bony trabeculae were continuous throughout, there could be no growth between the pseudoepiphysis and shaft at this stage.

The walls of the vascular canals were found to be similar in structure to the perichondrium from which they sprang, and, like the perichondrium, were chondrogenic, contributing new small-celled cartilage to the old.

Many canals had lost their vessels and become chondrified throughout, appearing as 'ghost' canals, which were wider than the vascularized canals from which they had been formed. Some ghost canals had lost their connexion with the perichondrium and formed 'floating ghosts'.

A basophilic network in the cartilage matrix round the canals was possibly related to loosening and stretching of the old cartilage to make more room for the new.

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